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Present situation and future prospect of hydropower in China

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ABSTRACT

Hydropower is a clean and renewable energy source. Considering the economic, technical and environmental benefits of hydropower, most countries give priority to its development. China has the richest hydro resources on the planet with a total theoretical hydropower potential of 694 GW. Developing hydropower is of great importance to alleviate the energy crisis and environmental pollution resulting from the rapid economic growth of China in the 21st century. This paper provides a survey of hydropower development in China. Over the last five decades, China's hydropower has developed quickly. The installed capacity of hydropower is 145.26 GW presently. Some large hydropower plants have been in operation and many are still under construction, including the Three Gorges Project (TGP) and pumped-storage power stations. Small hydropower development accelerates rural electrification of this country.

Contents

1. Introduction

1.1. Electricity demand in China

As a developing country, China's economy is growing at high speed. The gross domestic product (GDP) growth rate has maintained above 7% per year for a long period. By 2005 its GDP had reached 2225.7 billion US dollars (USD), with a per capita

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GDP of 1703 USD. The national economic growth is inevitably accompanied with an increasing demand for energy sources, one of which is the electricity [1].

By 2005, the total installed capacity of electric power had amounted to 508.41 GW, with an annual average generation of 2474.7 TWh. In spite of the huge quantity of electricity generation, the electricity supply had not met the demand well, which had led to load-shedding in many areas. This situation has been there for several years. Up to 2010, the electricity demand of China will touch 3810 TWh [2,3].

1.2. Present energy structure of China

In China, primary energy sources include the coal, petroleum, natural gas, nuclear, hydropower and other renewable energy sources (e.g. wind, solar, biomass and geothermal energy). Their compositions in the production and consumption of primary energy are shown in Table 1.

Obviously, the production and consumption of coal dominate the energy structure, whose shares both surpass 65%. Hydropower only occupies less than 7% of the energy production and consumption, respectively. This is incommensurate with the fact that hydro resources account for about 36.5% of the remained recoverable reserves of primary energy (others are: coal 58.8%, petroleum 3.4%, natural gas 1.3%) [4,5].

1.3. Hydropower

Hydropower is clean and renewable. At the present time, it is in fact the only clean energy source that can be commercially developed on a large scale. Furthermore, it accounts for about 20% of all electricity generated in the world and is utilized in more than 150 countries. Compared with other energy sources, the main advantages that hydropower offers are as follows [6,7]:

- Hydropower's "fuel" is essentially infinite and is not depleted during the production of electricity. Hydropower facilities simply harness the natural energy of flowing and falling water to generate electricity.
- Hydropower uses water to generate electricity. It is climate-friendly and does not produce air pollution or create any toxic by-products.
- Hydropower is the most efficient way to generate electricity. Today's hydro turbines can convert as much as 90% of the available energy into electricity. The best fossil fuel plants are only about 50% efficient.
- Hydropower can go from zero power to maximum output rapidly and predictably. This makes hydropower exceptionally good at meeting changing demands for electricity and providing ancillary electrical services that maintain the balance between supply and demand.
- Hydropower has the unique ability to change output quickly. Its unique voltage control, load-following, and peaking capabilities are critical for electric grid stability.
- Hydropower projects do more than just produce electricity; they create wildlife conservation lands, provide stable habitat for many kinds of wildlife, support healthy fisheries, provide water supply, control floods, irrigate land for food production, and create recreational opportunities for people.

2. Electric power development policy of China

After the reform of government agencies, the National Development and Reform Commission (NDRC) is in charge of the electric power industry. According to the resource status, the NDRC has formulated the electric power development policy, which is to develop hydropower with great efforts on the premise of protecting the environment and accomplishing the resettlement, optimize the thermal power, propel the nuclear power construction and actively promote the development of other renewable energy sources [8,9].

3. Hydro resources in China

China has large quantities of rivers, more than 50,000 of which cover a basin area over 100 km^2, and 3886 of which have hydropower potential over 10 MW. The research and investigation on hydro resources have been carried out for about 60 years in China. It experienced four large-scale general surveys, respectively in the years of 1950, 1955, 1980 and 2005 [10].

The 4th national survey of hydro resources ended in November 2005 indicates that the gross theoretical hydropower potential and annual average energy generation of China (mainland) are estimated as 694 GW and 6080 TWh/year, respectively. The technically exploitable installed capacity and annual average energy generation have been determined approximately as 542 GW and 2470 TWh/year, respectively, while the economically exploitable ones as 402 GW and 1750 TWh/year [11].

As to the regional distribution, Southwest China has the most fruitful hydropower resources in this country, which includes four provinces: Sichuan, Yunnan, Tibet and Guizhou. The second is for Mid-South China, and the last is for North China (Fig. 1).

4. Development status of hydropower in China

The first hydropower station in China was built with 500 kW installed capacity in 1912 in Shilongba, Yunnan Province. Only since the establishment of the People's Republic of China in 1949 has the hydropower developed rapidly [12].

4.1. Overall condition

By 2007, the installed capacity and energy generation of hydropower had totaled 145.26 GW and 486.7 TWh, about 891 and 685 times of the ones in 1949, respectively. The annual average growth rates were 12.4% and 11.9%, respectively. The volume doubles in less than 7 years. The share of hydropower in the total installed capacity rose from 8.8% in 1949 to 20.36% in 2007, while it decreased from 16.5% to 14.95% in the total energy generation (Table 2) [5,13].

In 2005, the installed capacity and energy generation of hydropower in China both ranked first in the world, and China also shared 13.3% of the world's hydro production. But the development level is only about 21.5%, far below the world

Table 1
Energy structure of China in 2005 [4]

	Coal (%)	Petroleum (%)	Natural gas (%)	Nuclear (%)	Hydropower (%)	Others (%)	Total (%)
Production	76.5	12.6	3.2	0.9	6.7	0.1	100
Consumption	69.1	21	2.8	0.8	6.2	0.1	100

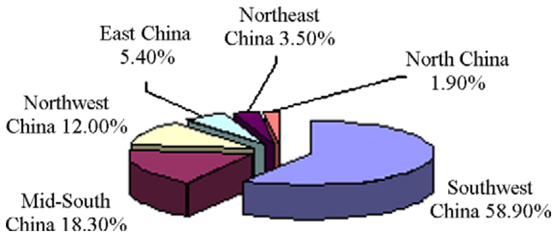


Fig. 1. The distribution of economically exploitable hydro resources in China [10,11].

Table 2
Growth of hydropower in China during the past 58 years [5,13,14]

Year	Installed capacity (GW)	Share (%)	Energy generation (TWh)	Share (%)
1949	0.163	8.8	0.71	16.5
1957	1.019	22.0	4.82	24.9
1965	3.02	20.0	10.41	15.4
1970	6.235	26.2	20.46	17.7
1975	13.428	30.9	47.63	24.3
1980	20.318	30.8	58.21	19.4
1985	26.42	30.4	92.4	29.0
1990	36.05	26.1	126.7	20.4
1995	52.18	24.0	186.8	18.6
2000	79.35	24.9	243.1	17.8
2002	84.56	24.0	271.0	16.5
2003	94.90	24.25	281.3	14.76
2004	108.26	24.57	328	15.00
2005	116.52	22.90	395.2	16.00
2006	128.57	20.67	416.7	14.70
2007	145.26	20.36	486.7	14.95

average. In addition, hydropower accounts for a minor share in the total electricity production. By contrast, Norway uses hydropower for 98.9% of its electricity, while Brazil and Canada produce 83.7% and 57.9% of their electricity with hydropower, respectively [5,15].

Till 2005, China had 21 large (capacity greater than 1000 MW) hydropower plants in operation, with a gross installed capacity of 39.73 GW, which accounted for about 34.2% of China's total. Moreover, 182 large and middle-scale hydropower plants are under construction, with a gross installed capacity of 92.5 GW. Among them, 35 are large-scale ones, whose total installed capacity amounts to 70.04 GW (Table 3) [5,10].

Most of these hydropower plants take energy generation as the primary purpose, and a few of them give priority to flood protection and irrigation, such as Wanjiazhai and Xiaolangdi hydropower plants.

Table 3
Major hydropower projects under construction in China [5]

Project	Province	River	Installed capacity (MW)	Average energy generation (TWh/year)
The Three Gorges	Hubei	Yangtze River	18,200	84.68
Wujiangdu	Guizhou	Wujiang	1250	4.06
Longtan	Guangxi	Hongshuihe	6300	18.7
Gongboxia	Qinghai	Yellow River	1500	5.14
Shuibuya	Hubei	Qingjiang	1840	3.92
Xiaowan	Yunnan	Lancangjiang	4200	18.89
Sanbanxi	Guizhou	Qingshuijiang	1000	2.43
Pubugou	Sichuan	Daduhe	3300	14.43
Goupitan	Guizhou	Wujiang	3000	9.53
Xiluodu	Sichuan	Jinshajiang	12,600	64
Laxiwa	Qinghai	Yellow River	4200	10.223
Jinping-1	Sichuan	Yalongjiang	3600	16.62
Pengshui	Chongqing	Wujiang	1750	6.3

4.2. Locations of the hydropower plants

Most hydropower plants of China are located in the provinces that are lack of coal or have an abundance of hydro resources, such as Liaoning, Jilin, Zhejiang, Fujian, Jiangxi, Hubei, Hunan, Guangdong, Guangxi, Chongqing, Sichuan, Yunnan, Guizhou, Shanxi, Gansu and Qinghai. In these provinces the installed capacity of each plant is greater than 1000 MW. Specifically, in Fujian, Hubei, Hunan, Guangxi, Yunnan, Tibet, Qinghai and Sichuan, the electric power generation from the hydropower accounts for over 30% of their respective totals. The development level, however, is not high. The highest is 88.6% for Hubei, and the second is 80.9% for Henan [5,16].

According to the distribution of hydropower resources, China has planned 13 hydropower bases (Fig. 2). They are Jinshajing River, Yalongjiang River, Daduhe River, Wujiang River, the Yangtze River Up Reaches, Qingjiang River, Nanpanjiang River and Hongshuihe River, Lancangjiang River, the Yellow River Up Reaches, the Yellow River Main, West Hunan, Fujian and Zhejiang and Jiangxi, the Northeast and Nujiang River. If the hydropower resources in these bases are completely developed, the installed capacity will amount to 275.77 GW [4].

Considering the hydropower resources, submergence, construction cost and other factors, China has given priority to developing the four following bases: the Yellow River Up Reaches, Hongshuihe River, the Yangtze River Up Reaches and Wujiang River. In 2000, China started the Western Development Program, one important part of which is to develop the hydropower resources in the remote and backward areas, such as Daduhe River, Lancangjiang River, Yalongjiang River and so on [4,17].

Many hydropower projects under construction are world-class ones. For example, the TGP is expected to have the largest installed capacity in the world, Jinping-1 Hydropower Project to have the highest double curvature arch dam (305 m), Shuibuya Hydropower Project to have the highest face rockfill dam (233 m), Longtan Hydropower Project to have the highest rolled compacted concrete gravity dam (216.5 m), and so on [4].

4.3. The pumped-storage power stations

By 2005, China had completed 11 pumped-storage power stations in 10 provinces. Their gross installed capacity reached 6.4 GW, which was about 1.3% of the total installed capacity of electric power. They include the following ones: Guangzhou (2400 MW, Guangdong), Tianhuangping (1800 MW, Zhejiang), Shisanling (800 MW, Beijing), Panjiakou (270 MW, Hebei), Baishan (300 MW, Jilin), Shahe (100 MW, Jiangsu), Xikou (80 MW, Zhejiang), Xianghongdian (80 MW, Anhui), Tiantang (70 MW, Hubei), Huilong (120 MW, Henan), and Yangzhuoyong Lake (90 MW, Tibet). Moreover, 10 pumped-storage power stations are under construction (Table 4) [5].

4.4. Small hydropower

The technically exploitable capacity of small hydropower (with installed capacity of less than 50 MW) in China is estimated as 128 GW, with an average energy generation of 450 TWh/year. It is widely distributed in more than 1600 mountainous counties around the country. West China accounts for 67.6% of the total capacity, while for Central China and East China, the shares are 16.8% and 15.6%, respectively [5,10].

With the rural economic growth and governmental support, the small hydropower has developed rapidly. By the end of 2005, small hydro projects had had an installed capacity of 38 GW and an annual average generation of 130 TWh, which was about 32.9% of

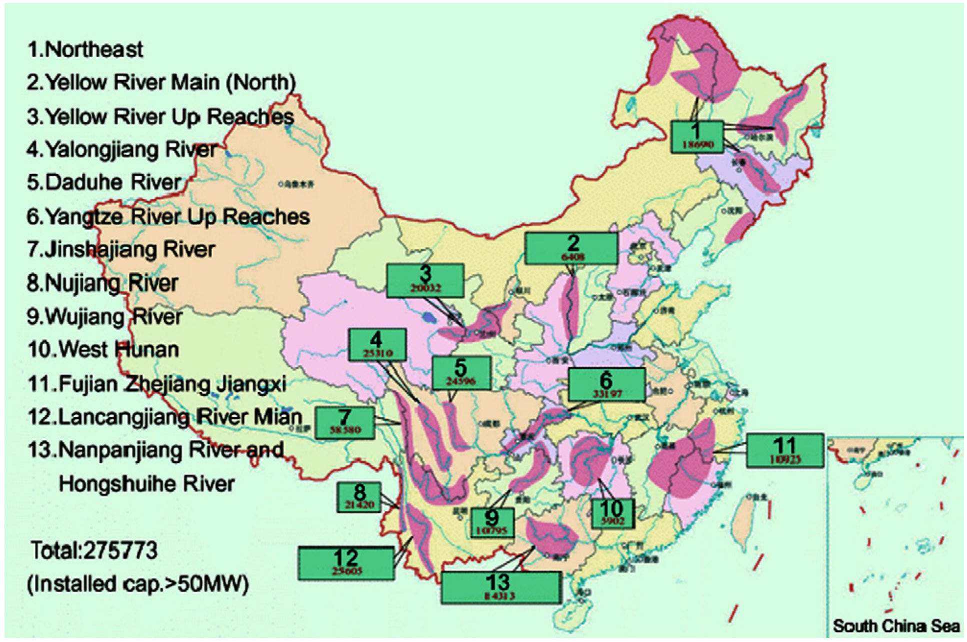


Fig. 2. Locations of 13 hydropower bases in China (http://www.checc.cn/English/pages/Hydropower/Hydropower.jsp).

the total hydropower generation capacity in that year. More than 40,000 small hydropower plants had been built, and 653 rural counties had achieved preliminary electrification. The development level of small hydropower is higher than that of the large and middle-scale hydropower. Furthermore, 15 small hydropower bases are under construction, with an installed capacity of not less than 1000 MW for each (Table 5) [4,18].

4.5. The Three Gorges Project (TGP)

The TGP is the biggest hydropower project in the world. It is of great importance for China to harness and develop the Yangtze River. After about 70 years' argumentation and planning, China began the construction of this project in 1994 [17].

The dam site of the TGP is located at Sandouping, Yichang, Hubei Province. The project is composed of three parts: the key project, the reservoir project and the transmission project. The key project mainly includes the dam, powerhouses of the hydropower plant, the ship lock and ship lift. The normal pool level for the reservoir is 175 m with the dam crest level at 185 m. Its total storage capacity amounts to 39.3 billion m^3, of which 22.15 billion m^3 is the flood control capacity. The hydropower plant will be installed with 26 hydro-turbine generating units with a rated capacity of 700 MW for each, and the installed capacity totals 18.2 GW. It is estimated to have an annual average energy generation of 84.68 TWh [17,19].

The total investment of TGP is about 180 billion RMB Yuan, among which 40% is from the TGP Construction Fund, and 20% is from the generation revenue of Gezhouba hydropower plant and the TGP during construction. The remaining 40% of capital, however, is raised from the financial market through multi channels, such as bank loans, public issuance of bonds, and so on [8,20].

The construction of TGP is projected to take 17 years, which are divided into three stages (Table 6). From 2003 to 2005, 6, 5 and 3 generating units were put into operation, respectively. In those three years, the TGP respectively generated 8.61, 39.16 and 49.09 TWh of electricity, alleviating the electricity shortage of China [19,21].

5. Restrictive factors for hydropower development

5.1. Unevenness of precipitation distribution

The temporal and spatial distribution of precipitation is badly uneven in China, which is disadvantageous to develop the

Table 4
Major pumped-storage power stations under construction in China [5]

No.	Project	Location (province)	Installed capacity (MW)	Average energy generation (TWh/year)
1	Tongguanshan	Jiangsu	1000	1.49
2	Tai'an	Shandong	1000	1.338
3	Xilongchi	Shanxi	1200	1.805
4	Baoquan	Henan	1200	2.01
5	Zhanghewan	Hebei	1000	1.675
6	Tongbai	Zhejiang	1200	2.118
7	Langyashan	Anhui	600	0.856
8	Bailianhe	Hubei	1200	0.967
9	Hemifeng	Hunan	1200	1.606
10	Huizhou	Guangdong	2400	4.563

Table 5
Small hydropower bases under construction in China [4]

No.	Base	Location (province)
1	Shaoguan	Guangdong
2	Qingyuan	Guangdong
3	Sanming	Fujian
4	Longyan	Fujian
5	Ningde	Fujian
6	Lishui	Zhejiang
7	Chenzhou	Hunan
8	Ganzhou	Jiangxi
9	Ya'an	Sichuan
10	A'ba	Sichuan
11	Liangshan	Sichuan
12	Guilin	Guangxi
13	Shiyan	Hubei
14	Enshi	Hubei
15	Yichang	Hubei

Table 6
Three stages of the TGP construction [19]

Stage	Duration (years)	Year–year	The main work
I	5	1993–1997	The earth and rock filling of stage I cofferdam, and the open diversion channel excavation, including the preparation work
II	6	1998–2003	The construction of stage II cofferdam, power plants on left bank and the installation of generating units
III	6	2004–2009	The construction of the dam and power plants

hydropower. The uneven precipitation in time not only makes the river flow vary dramatically within one year from the flood season to dry season, but also may lead to continuous dry or wet years. If reservoirs are built to regulate the river flow, the demanded storage capacity will be very huge, and the problems of investment and resettlement are difficult to solve. Uneven precipitation in space leads to the concentration of hydro energy in the west of China. Thus the long-distance and extra-high-voltage transmission lines between the west and the east should be built, which increases the investment and causes many other problems too [10,22].

5.2. Resettlement and negative impact on the environment

Except some low-head run-of-water power plants, hydropower cannot be done without constructing dams and reservoirs, which causes the inevitable submergence of lands and resettlement. Moreover, it will bring some negative influence on the ecosystem. Since China is a country with a huge population, limited land and fragile ecosystem, these factors undoubtedly increase the difficulty for hydropower development [11,22].

6. Future prospect

On September 5, 2007, the NDRC of China issued the Medium and Long-term Plan of Renewable Energy Source Development to meet the growing energy demand, improve the energy structure and reduce environmental pollution. Up to 2020, the gross installed capacity of hydropower will reach 300 GW, 225 GW of which will be from the large and middle-scale hydropower, while 75 GW from small hydropower [9].

On March 18, 2008, the NDRC announced the Eleventh Five-year Plan of Renewable Energy Source Development. An additional 73 GW of hydropower will be installed during the Eleventh Five-year period (2006–2010), 13 GW of which will be from the pumped storage power stations. By 2010, the total installed capacity of hydropower will reach 190 GW, 120 GW of which will be from the large and middle-scale conventional hydropower, 50 GW from small hydropower, and 20 GW from the pumped-storage power stations. The installed capacity of conventional hydropower that will have been constructed by 2010 will account for 31% of the technically exploitable installed capacity of China's total [4].

7. Conclusions

Hydropower is a renewable energy source with low generation cost and high efficiency. Development of hydropower can increase the clean energy supply and reduce the emission of greenhouse gases, which is helpful to establish a sustainable energy system and maintain the socio-economic development.

China is affluent in hydropower resources and has rather high development potential in hydropower. With the great efforts made by China, it can be foreseen that from now on hydropower development in this country will enter a new stage. Up to 2050, most technically exploitable hydropower resources in China will have been utilized. It will play a more important part in the economic development and global environmental protection.

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